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OPERATOR TRAINER (OPTRAIN): THE UNITED STATES (U.S.) ARMY AERIAL TARGETS SIMULATOR AND TRAINER

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13. ABSTRACT ***(Maximum 200 Words)*** The Operator Trainer (OpTrain) program is an integral tool for simulation and training used by the United States (U.S.) Army to support their high-speed aerial targets. The program is comprised of three main sections: a Six Degrees-Of-Freedom (6-DOF) simulation, target and terrain graphics, and the user interface. Each of these provides operators with a powerful tool that has the ability to record and display flight data, flight instrumentation, and vehicle animation. It can be used for operator proficiency training, mission rehearsal, real-time flight visualization, and playback of flight data. An array of conditions can be modified, including atypical winds, towed payloads, and actuator faults, in addition to many 6-DOF simulation inputs. The methodology and usages of the simulator and training software are presented.			
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I. INTRODUCTION

Unmanned targets for air-, ground-, and sea-based systems are used extensively by modern military nations around the world to conduct research, development, and testing of a variety of technologies. Aerial target systems, in particular, have provided the United States (U.S.) military with affordable devices to impersonate, test, and evaluate missile systems. Over the years, the capabilities have increased dramatically. Aerial targets now range from miniature to full scale and can be fixed or rotary wing with several reaching supersonic speeds.

While each of the U.S. military branches has its own organizations to manage and promote the use of targets, the organization responsible for the Army's target systems is the Program Executive Office for Simulation, Training, and Instrumentation (PEO-STRI). The organization was created in 1974 and designed to develop new training technologies during the Cold War. Since then, PEO-STRI has grown exponentially and encompasses nearly a dozen project offices, including the Program Manager (PM) Instrumentation Targets and Threat Simulators' Targets Management Office (TMO), which manages aerial and ground targets [1]. The TMO's mission is to provide technically advanced targets with the best value and superior life-cycle operations and sustainment support for the Army, the other joint services, and foreign customers.

Known as the Army's workhorse, the most versatile subscale aerial target in the TMO repertoire is the MQM-107 Streaker, as shown in Figure 1. It is capable of performing advanced maneuvers up to transonic speeds. With its external payload and towing capabilities, it has the ability to simulate practically any air defense threat. The MQM-107 was developed in 1972 by Beechcraft for the Army's Variable Speed Training Target design competition. Beech won the competition in 1975, and the MQM-107A began full production that year [2].

Figure 1. MQM-107 Streaker Launch with Tows

The A model was replaced in 1982 with the longer B model. It had an increased payload volume and a more powerful engine (the Microturbo TRI 60-2) that increased the maximum speed. Limited C models came next and created a means to deplete excess parts from the stock of A and B engines and fuselages. The D and E models are still in service and have been used by the U.S. Army and Air Force since their introduction in 1987 and 1994, respectively. The production contract for the MQM-107E was initially awarded to Tracor (now BAE Systems). In 1979, the Beech Aircraft Corporation was taken over by Raytheon, which continued the work with the MQM-107. In recent years, however, Composite Engineering, Inc. (a longtime components producer for the MQM-107) purchased the rights to produce the targets from Raytheon.

During the development of the later MQM-107 models, Beechcraft (a Raytheon company) developed Six Degrees-of-Freedom (6-DOF) flight simulation software for the MQM-107 system. The program was designed to simulate the aircraft in translational and rotational degrees-of-freedom throughout all aspects of flight, including surface launch, climbs, dives, turn maneuvers, and recovery [3]. In the early 1990s, the simulation code was given to the U.S. Army Aviation and Missile Research, Development, and Engineering Center (AMRDEC) for internal use and development and given the name Stealth. Since then, the System Simulation and Development Directorate (SSDD), in conjunction with contractor Torch Technologies, Inc., has dramatically expanded the capabilities of the simulation and continues to make it a state-of-the-art software program that is essential for each of the Army's MQM-107 missions and operator proficiency training. An early version of the Stealth from 2003 is shown in Figure 2.

Figure 2. Stealth V4.4 Display

Throughout the 1990s and 2000s, the Aerial Targets Laboratory (SSDD and Torch) redesigned and modernized the simulation and training program known as the Stealth. The Stealth offered customers a single tool for engineers and operators to simulate the MQM-107 target, with the Beech code as its backbone. In 2011, the Stealth program was officially retired. The Operator Trainer (OpTrain) and Simulation Study (SimStudy) programs replaced the Stealth program and allowed developers to cater the software to two distinct user groups: target operators and engineers. The OpTrain is designed primarily for field operator training, while SimStudy caters to engineering and data analysis. This provides for increased flexibility and efficiency in meeting the various user groups because requirements and expectations often differ.

II. OPTRAIN AERODYNAMIC TOOLS

The OpTrain simultaneously runs three executables: Graphical User Interface (GUI), 6-DOF simulation, and Three-Dimensional (3-D) target and world view rendering.
The original 6-DOF simulation implements MQM-107 E model aerodynamics. It was developed in the Fortran programming language, while the autopilot code was written in C. A Fortran-to-C interface written in digital Fortran allows the 6-DOF to call the C autopilot. Since Beech delivered the code, AMRDEC software developers have improved the actuator model, converted large portions of the code from Fortran to C, and integrated the digital avionics package. All of the Fortran code has been optimized to run at or faster than real time. An additional Rocket-Assisted Takeoff (RATO) model and several tow target payloads have also been added. The MQM-107 E and D are modeled in the program. Since the fiscal year 2012, additional targets from the Army and Navy continue to be incorporated as a user need arises, such as the BQM-34S (Army variant), BQM-74E (Navy variant), and Pioneer Unmanned Aerial Vehicle (UAV).

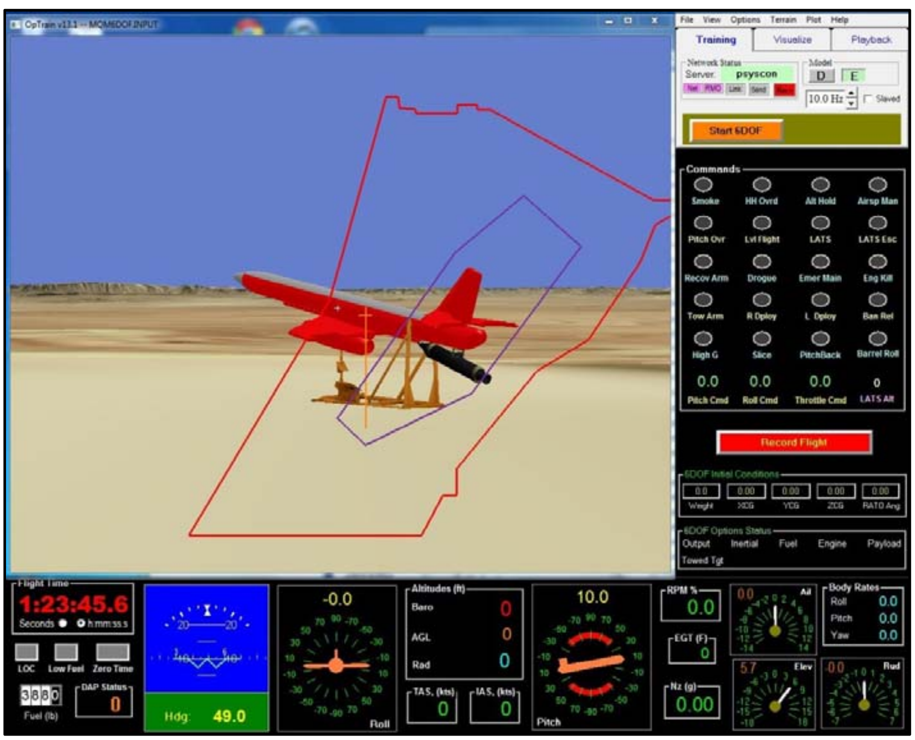


Figure 3. OpTrain Display

The GUI provides a 6-DOF Options window. Users now have the ability to modify 6-DOF input parameters without directly altering the input file code. Inertial parameters, fuel weights, virtual payloads, and RATO attachment angles are among the options. Significant effort has gone into the implementation of the payload and RATO capabilities. The OpTrain has the capability to simulate an MQM-107 carrying a virtual internal payload simulated by adding a mass and adjusting the Center of Gravity (CG) or a number of external towed and non-towed targets. For accurate flight models with realistic drag and inertial data, the targets were individually modeled in the MissileLab program. MissileLab is a Visual Basic GUI developed within AMRDEC's SSDD that assists users in running several aerodynamic prediction codes. Sets of geometric and atmospheric conditions for each towed target, normalized by the MQM-107s reference CG and dimensions, were input into MissileLab, as shown in Figure 4 [4].

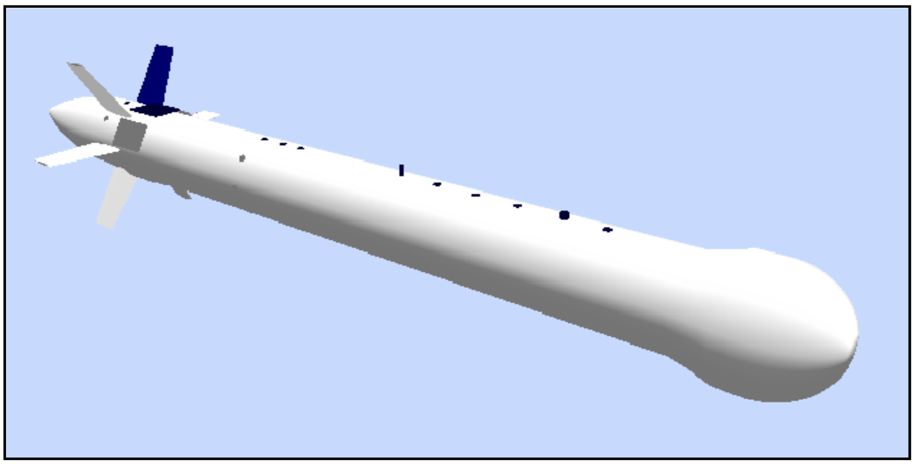


Figure 4. JCHAAT MissileLab Produced 3-D Model

The moments of inertia were determined through pendulum testing in the Aerial Targets Laboratory. The tow was balanced on a knife edge stand to determine the CG, and a pendulum system was clamped to the tow at the CG. Clamping at $\theta = 180$ degrees is used for IZZ and IYY; clamping at 90 degrees is used for IXX measurements. The pendulum and tow assembly were hung on a frame, as shown in Figure 5. Swinging the pendulum at small amplitudes and measuring the time determined the natural period that, along with the mass, can be used to determine the moments of inertia.

Figure 5. JCHAAT Tow Swing Setup

The MissileLab program utilizes Missile Datcom to produce a table of aerodynamic coefficients for a range of airspeeds and altitudes [5]. These data, along with the targets mass properties determined through laboratory testing, are incorporated into the 6-DOF flight simulation via a separate input file that OpTrain calls when a tow is selected from the GUI. For each of the towed targets, data for the cable tension, drag, and attachment angle are generated from the Cable-Body Aerodynamic Simulation (CBAS) derived program. The CBAS, originally known as Cable-Body Underwater Simulation (CBUS), was developed in 1984 by Bath University in the United Kingdom [6] to analyze the behavior of bodies (fish) towed underwater. The CBUS was later modified in a multinational effort between the United Kingdom's Ministry of Defense, the U.S., and Australia for use with aerial towed systems and became known as CBAS [7]. The version currently in use was a follow-on to the prior effort where the Aerodynamic Research Laboratory of Australia updated and improved cable modeling capabilities and fixed instabilities within the program.

The CBAS program is based on a Newton-Euler form of the equations of motion and accounts for the towing aircraft, tow cable, and towed body [8]. In the 1990s, AMRDEC developed a basic version known as CBAS Junior (CBASJr) that simplified the equations by considering only Two-Dimensional (2-D) aerodynamics along the X- and Z-axis. A plot of the CBASJr calculated droop and tension for a Japanese CHU-SAM Advanced Aerial Tow (JCHAAT) is shown in Figure 6.

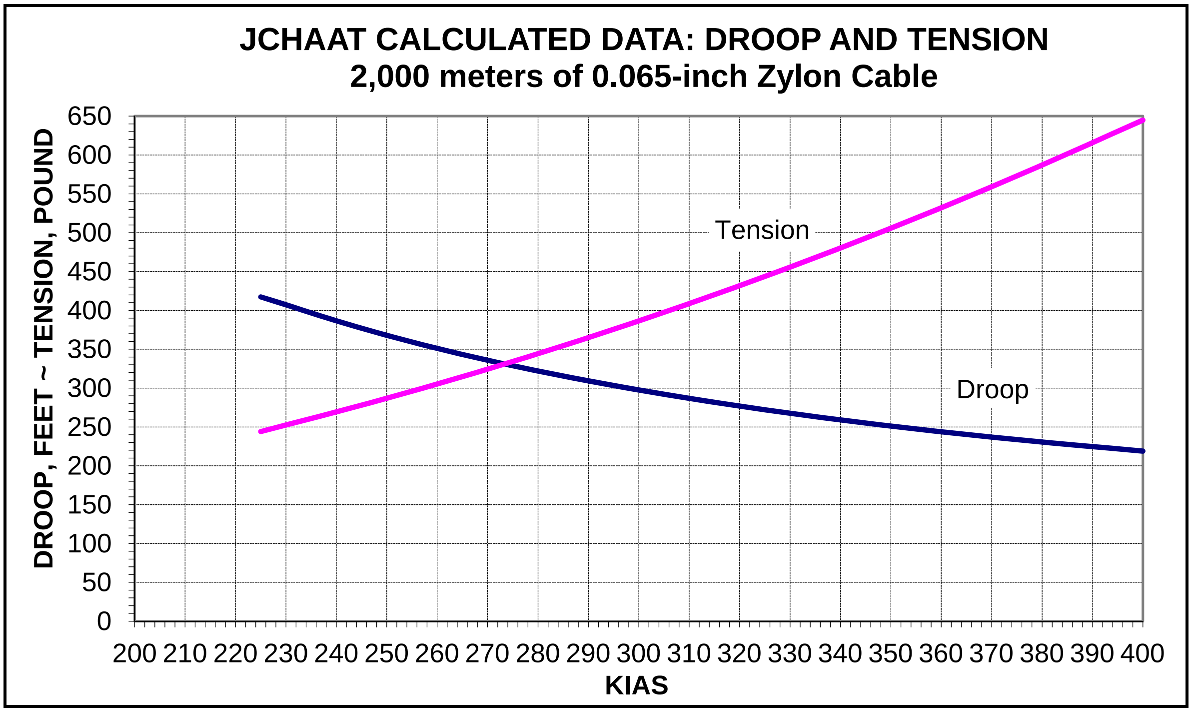


Figure 6. CBASJr Produced Droop and Tension for JCHAAT Target

The data tables input into the towed target input file for OpTrain are based on the towlines that are most commonly used for each particular tow. For instance, the TIX-4 is most often towed with 5,000 feet of 0.050-inch diameter Zylon, while the TRX-4A is towed with 8,000 feet of 0.032-inch diameter steel. This is critical as the drag on the tow line is typically an order of magnitude higher than on the tow itself. The simulation is tailored for each tow's typical towing setup, but the user can modify the data file to change the tow line type and length.

Extensive work was done with OpTrain leading up to the ultimately successful testing of alternative engines for the MGM-107 including the Williams WJ38-15 and Microturbo TRI 60-5+. The Microturbo TRI 60-5 model turbojet engine is standard on MQM-107 flights. It is throttled to 95 percent at launch, supplying approximately 800 pound force of thrust. Because the MQM-107 is ground launched from a zero-length launcher, a RATO is required to provide more thrust and impulse to launch the drone and achieve steady flight. An additional 5,800 pound force of thrust is supplied by the standard SR-121 or Bristol RATO during its 2.5-second burn. The head end RATO mount utilizes an internal spring to disengage a RATO when the supplied thrust is less than 300 pound force, after which the RATO falls to the ground. The RATOs are shown in Figure 7.

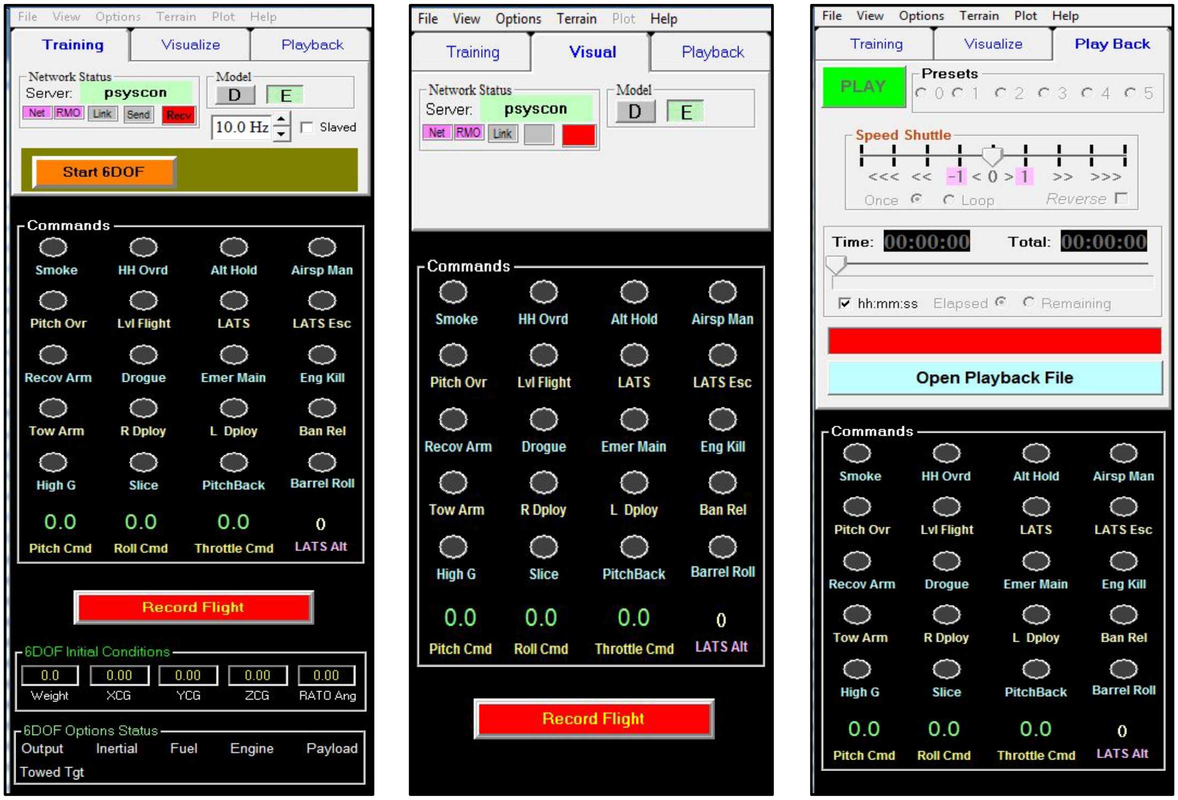
a. SR-121 *b. Bristol*

Figure 7. RATO Motors for MQM-107

A critical aspect of the simulation is the RATO attachment angle, which is defined by the angle between the centerlines of the MQM-107 and RATO through which the RATO forces act. A difference of a few degrees can cause the aircraft to suffer severe nose-up or nose-down movements during the RATO burn that can ultimately result in the loss of the aircraft. The angle must be set to balance the pitching moment. A nose-up moment is produced by the turbojet since it is below the centerline of the MQM-107. The RATO thrust vector must pass just above the CG of the system. Beechcraft relied on a series of flight tests in the 1970s to determine RATO attachment angles. The angle for the Bristol RATO was determined by simulation in SimStudy and verified during flight testing.

III. OPTRAIN OPERATIONAL MODES

There are three modes of operation within OpTrain, each specifically designed to provide users with a unique capability. Prior to flight testing, flight controllers use different OpTrain modes to simulate and rehearse for missions without having to incorporate or sync to the actual aircraft. The modes utilized by mission controllers are the training, visualize, and playback modes. The GUI panels for each mode are shown in Figure 8. The Commands box common to the three modes displays the telemetry data as OpTrain receives it. The indicators show what is being commanded from the ground station’s command panel. For Playback mode, the commanded data are embedded within the playback file.



a. Training Mode *b. Visualize Mode* *c. Playback Mode*

Figure 8. GUI Panels

The Training mode provides an opportunity to use the ground station control panel and associated software during training. The OpTrain provides a simulation that responds to the operator's panel interactions which allows the operator to gain valuable experience using the control panels that will be used during flights. The simulation responds to the commands and transmits a corresponding set of telemetry data to the ground station network. Trainers use OpTrain to transmit conditions and simulate faults to ground station system while the trainees adapt and attempt to maintain control via the operator's Telemetry Display System (TDS) and Position Display System (PDS). This prepares them for encountering problems during an actual flight.

The Visualize mode provides a 3-D synthetic representation of an actual flight derived from downlinked telemetry flight data provided by the ground station network. The 3-D model will "fly" along with the actual aircraft in real time, showing its world location and telemetry data. The flight can be recorded and played back for future study. The OpTrain is simply observing and displaying what is happening in real-time. No data are calculated or transmitted during this mode's operation.

The Playback mode plays back any file recorded by OpTrain or any actual flight data that has been converted to the OpTrain playback format. The Playback mode is extensively used in crash investigations and post-flight analysis. The Command status buttons are illuminated on the

GUI to show when commands were initiated and what maneuvers and modes were active throughout the flight, which assists not only engineers but operators as well.

IV. COMPUTER NETWORKING

The OpTrain is run in conjunction with the Army Target Common Control System (ATCCS) ground station. The ATCCS is a prototype system being developed for the U.S. Army to address the Defense Science Board's 2005 recommendation that all services migrate to a future common control system so they can test on all major ranges [9]. The Army Ground/Aerial Target Control System (AGATCS) will be the final product and is expected to be fielded around the world in fiscal year 2017. The AGATCS will be able to control several of the major subscale and full-scale ground and aerial targets using a common datalink interface.

The ATCCS is comprised of four computers; however, of which one is dedicated solely to hosting the simulation and training software. The remaining computers run position and telemetry displays, the radio frequency module, and the system console [10].

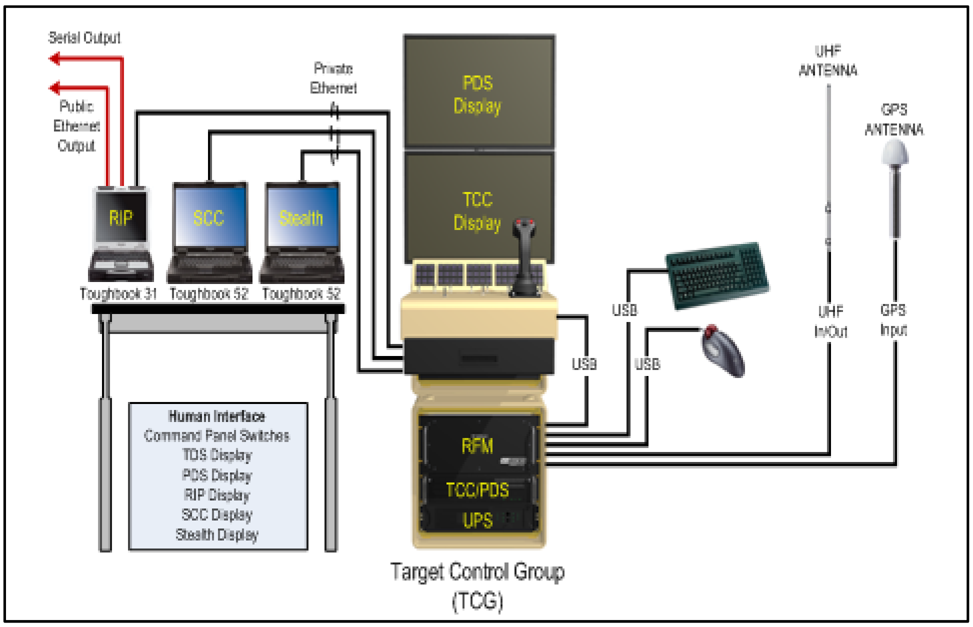


Figure 9. ATCCS System Diagram

The PDS contains maps of flight areas with boundaries, launch, and recovery markings. It is also used to construct Rabbit Follower tracks, which are pre-defined flight patterns that direct the target in real time to a moving space point along the tract, referred to as the "rabbit." Operators maintain the capability to vary mission control parameters in real time, such as target and formation velocity, cross track deviations from the predefined flight pattern, and the minimum airspeed allowed [11]. Figure 10 shows the PDS map that was used at the MQM-107 launch facility at McGregor Range on Fort Bliss. The TDS displays telemetry data and gauges, as shown in Figure 11. The radio frequency module screen contains all of the ultra-high frequency radar uplink and downlink hardware and software, as shown in Figure 12.

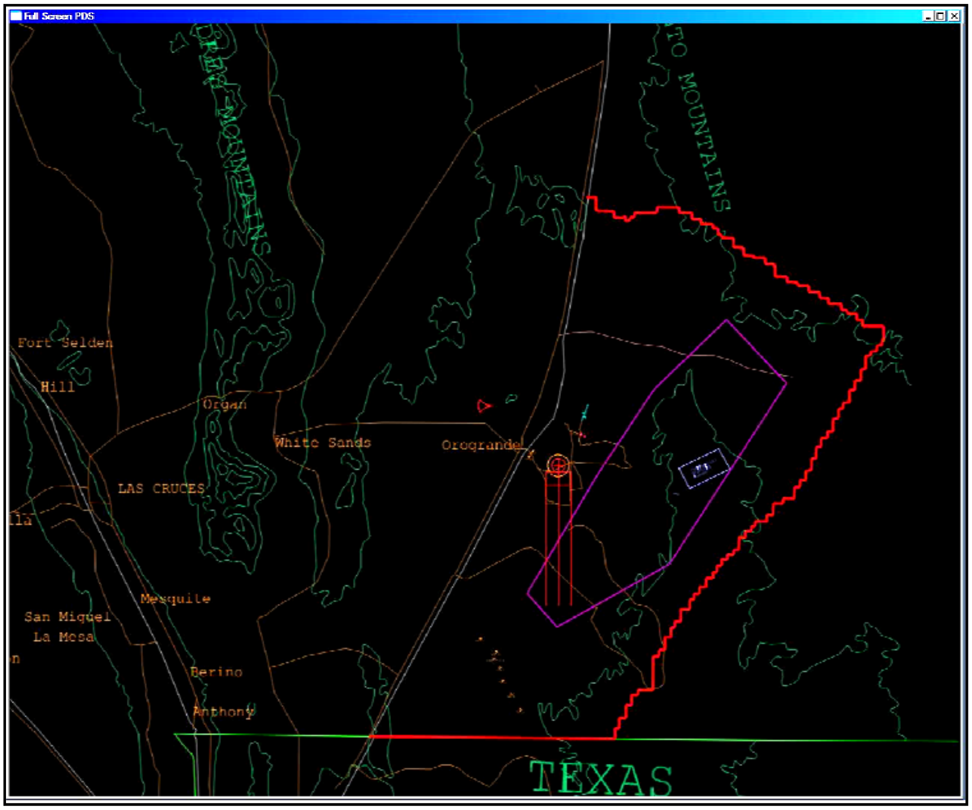


Figure 10. PDS Display

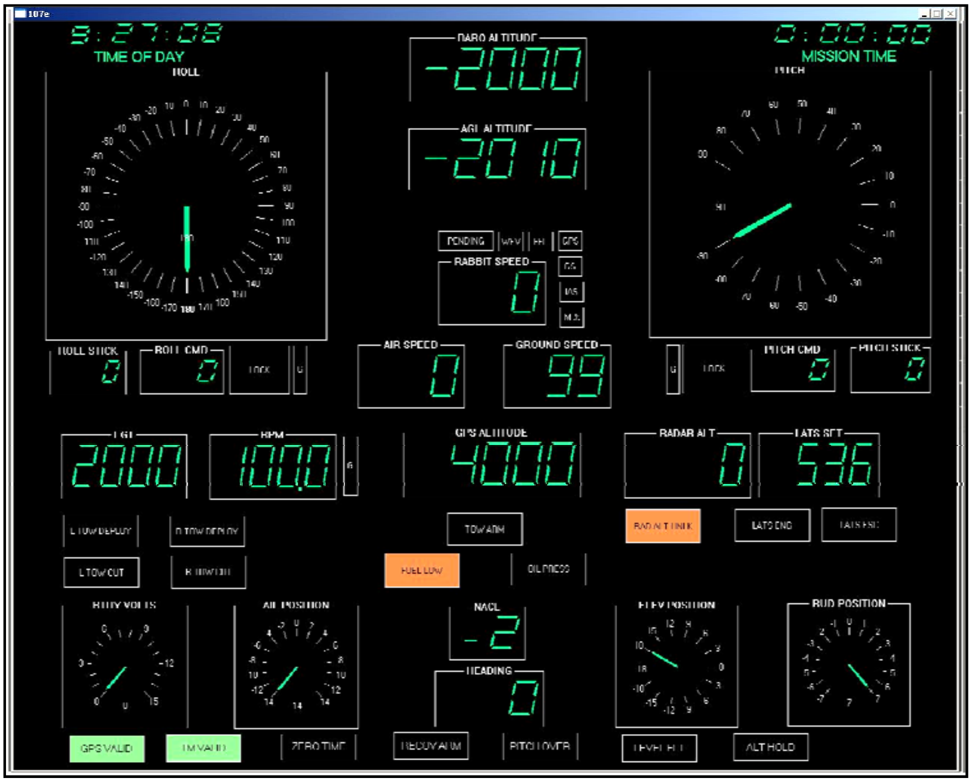


Figure 11. TDS Display

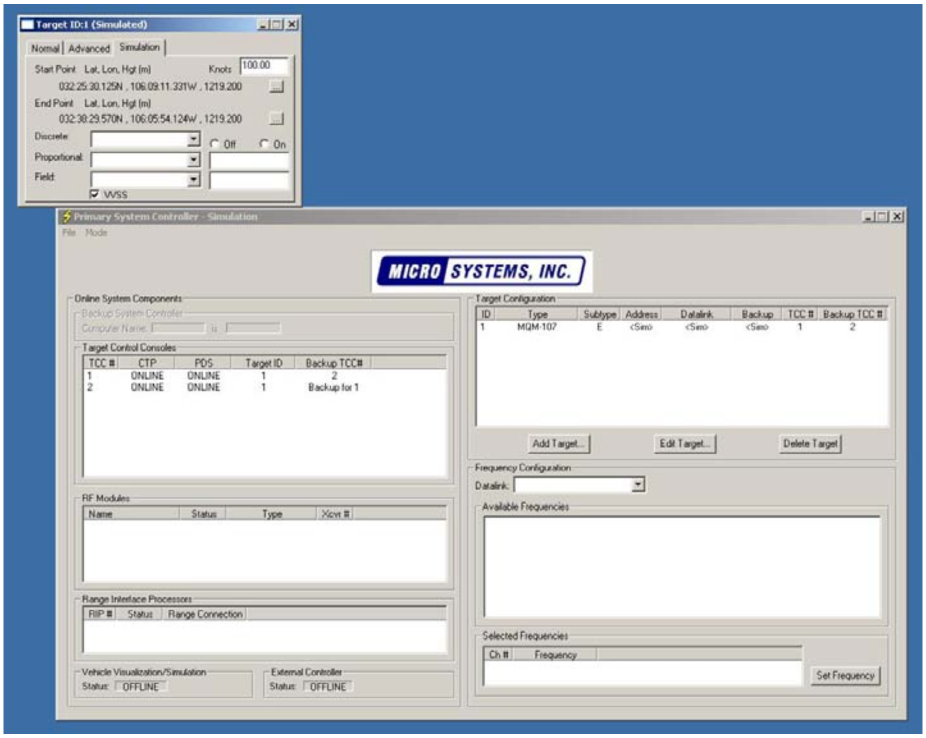


Figure 12. Syscon Setup Screen

All data transfers on the ATCCS/OpTrain network connection are serialized reverse-message-order messages that are sent over the network by means of universal telemetry and universal command blocks. The universal telemetry block is a fundamental unit for a block of telemetry, that encapsulates a target identifier, a variable number of discrete, proportional and field telemetry, and a time-tag validity indicator. The universal command block is the fundamental unit for a block of commands that encapsulates a target identifier, a variable number of discrete, proportional and field commands, a time tag, and a time-tag validity indicator. In Visualization mode, OpTrain accepts target time-space-position information and telemetry from the ATCCS. In Training mode, OpTrain accepts target commands from the ATCCS. The OpTrain processes these commands and simulates the target accordingly. The simulated target time-space-position information and telemetry are sent back to the ATCCS for the purpose of display.

V. CONCLUSION

Additional 6-DOF models will be incorporated into OpTrain that will improve the accuracy of the simulation. Upgraded networks will improve the communicative abilities of OpTrain and the ATCCS. The OpTrain continues to be updated to mimic the ever-improving capabilities of the MQM-107 and other target systems with more user-modifiable options and improved ease-of-usability.

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LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

#	Number
2-D	Two-Dimensional
3-D	Three-Dimensional
6-DOF	Six Degrees-of-Freedom
Acc	Acceleration
AGATCS	Army Ground/Aerial Target Control System
AGL	Above Ground Level
Airsp	Airspeed
Alt	Altitude
AMRDEC	Aviation and Missile Research, Development, and Engineering Center
Ang	Angle
ATCCS	Army Target Common Control System
Ban Rel	Banner Release
Baro	Barometer
BTRY	Battery
CBAS	Cable-Body Aerodynamic Simulation
CBASJr	Cable-Body Aerodynamic Simulation Junior
CBUS	Cable-Body Underwater Simulation
CG	Center of Gravity
Ch	Channel
Cmd	Command
DAP	Digital Autopilot
Depl/Dploy	Deploy
dg	degree
Dist	Distance
E	East
EGT	Exhaust Gas Temperature
Elev	Elevator
Emer	Emergency
Eng	Engine
ESC	Escape

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS (CONTINUED)

F	Fahrenheit
FT/ft	foot
g	gravity
GPS	Global Positioning System
GS	Ground Speed
GUI	Graphical User Interface
h:mm:ss.s	hour:minute:second
Hdg	Heading
Hgt	Height
HH	Heading Hold
Hi	high
Hz	hertz
IAS	Indicated Airspeed
ID	Identifier
JCHAAT	Japanese CHU-SAM Advanced Aerial Tow
KIAS	Knots Indicated Air Speed
kt	knot
L	Left
Lat	Latitude
LATS	Low Altitude Threat Simulator
LB/lb	pound
LOC	Loss of Carrier
Lon	Longitude
Lvl	Level
m	meter
Man	Maneuver
N	North
NACL/ Nz	Normal Acceleration
NE	Northeast
NW	Northwest
OpTrain	Operator Trainer

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS (CONTINUED)

Ovr	Over
Ovrd	Override
PDS	Position Display System
PEO-STRI	Program Executive Office for Simulation, Training, and Instrumentation
PM	Program Manager
psyscon	Primary System Controller
R	Right
Rad	Radar
RATO	Rocket-Assisted Takeoff
Recov	Recovery
Recv	Receiver
RFM	Radio Frequency Module
RIP	Remote Interface Processor
RMO	Reverse Message Order
Rud	Rudder
S	South
SCC	System Control Console
SE	Southeast
Secs	Seconds
Sim	Simulation
SimStudy	Simulation Study
SSDD	System Simulation Development Directorate
SW	Southwest
TAS	True Airspeed
TCC	Target Control Console
TCG	Target Control Group
TDS	Telemetry Display System
Tgt	Target
TM	Telemetry
TMO	Targets Management Office
UAV	Unmanned Aerial Vehicle

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS (CONCLUDED)

U.S.	United States
UHF	Ultra-High Frequency
USB	Universal Serial Bus
V	Version
VVSS	Vehicle Visualization System Simulation
W	West
XCG	X-Axis CG
YCG	Y-Axis CG
ZCG	Z-Axis CG

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